Dynamics of the Mars Atmosphere: The Post-Viking Perspective

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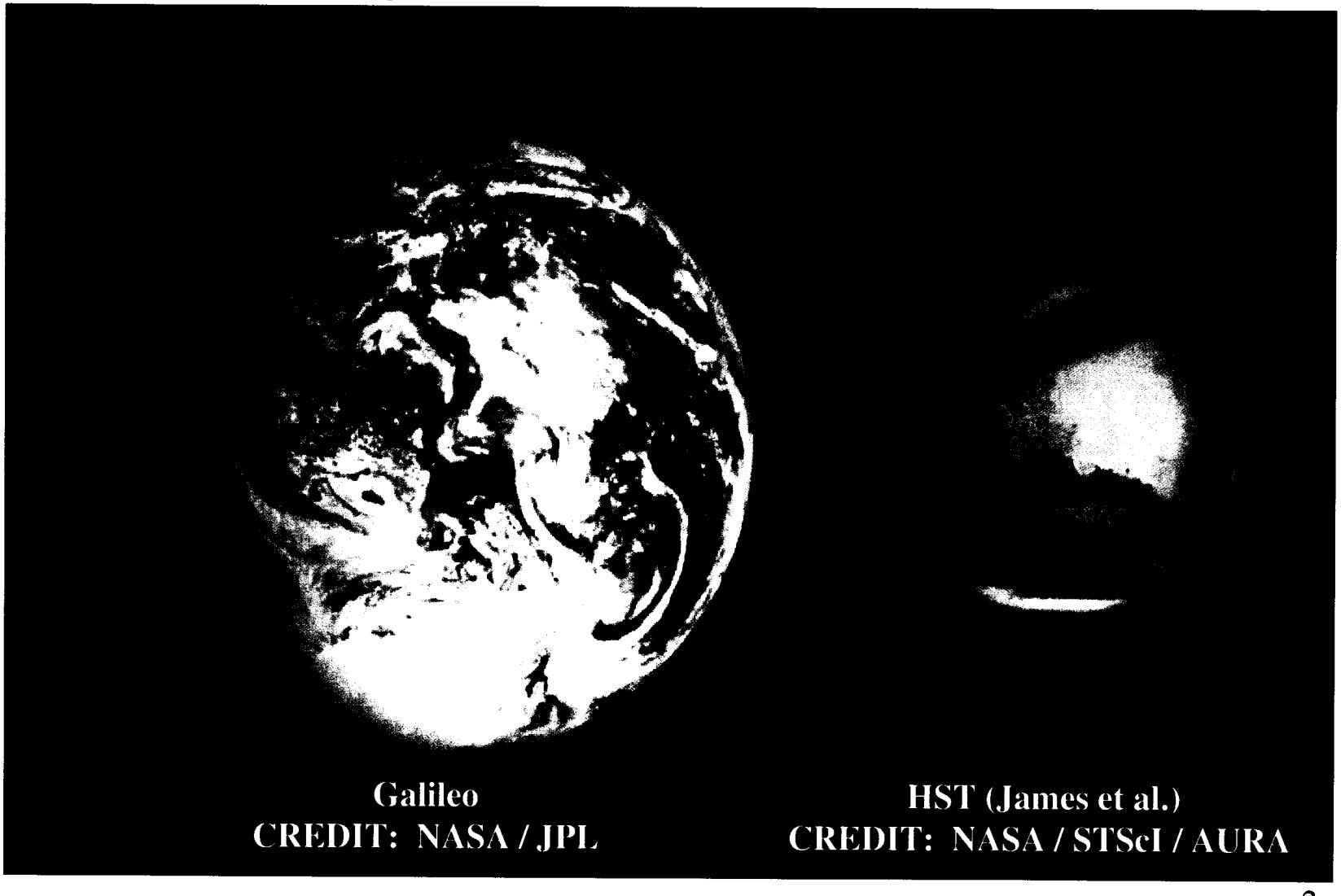
****Work performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration***

Earth & Mars

— *Mars Reference Atmosphere*



Galileo
CREDIT: NASA / JPL

HST (James et al.)
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1982 COSPAR Mars Reference Atmosphere (1)

- ***Post-Viking Models of Summer Atmospheric Structure***
  - **2 Viking Entry Profiles**
  - **Seasonal Variation of Surface Pressure**
- ***Martian Meteorological Variability***
  - **Seasonal wave phenomena in lower atmosphere**
  - **Diurnal and semidiurnal atmospheric tides (daily variations in V,T,P)**
  - **Surface wind measurements at the two Viking Lander sites**
  - **Evidence in cross-equatorial Hadley circulation in T, sfc. P**
  - **Heavy reliance on models to interpret data**
- ***Properties and Impact of Dust in the Martian Atmosphere***
- ***IRTM: Temperature and Dust from IR data***
  - **Wintertime Polar Warmings**
  - **Dust opacities from thermal IR data**
  - **Diurnal ground temperature variations**

1982 COSPAR Mars Reference Atmosphere (2)

- ***Clouds of Mars***
  - **Dust hazes, local dust storms and major dust storms**
  - **Condensate clouds: orographically forced, polar hood, storms**
  - **Surface frosts (snow?)**
- ***Composition***
- ***Water Vapor (column abundances for most of a Mars yr.)***
- ***Mars Upper Atmosphere: Mean and Variations***
  - **Dust Storm effects**
  - **Diurnal variations**
  - **Solar Cycle Variations (Mariners 6, 7, 9, and Viking)**
- ***Upper Atmosphere Wave Structure***
  - **High altitude wave structure (in temperature profiles)**

1992 MARS Book: Issues in Atmos. Dynamics

— *Mars Reference Atmosphere*

- **Hadley-type Circulations**
  - ***Strength, Extent, Nature (e.g., 1 cell or 2 at equinox; vertical range)***
- **Atmospheric Waves**
  - ***Strength of wave activity at high southern latitudes during winter***
  - ***Influence of topography (orography and variations in surface A,I)***
  - ***Influence of gravity waves and nature of polar warmings***
- **Dust Cycle**
  - ***The nature of great dust storms and their interannual variation***
  - ***Feedback mechanisms***
- **Role of Transport in Water and Carbon Dioxide Cycles**
  - ***Transport of mass and of heat into and/or out of the polar regions***
- **Improvements in Atmospheric Modeling**
  - ***Increased spatial resolution and vertical range***
  - ***Better parameterizations of dust movement, injection and removal***

Atmospheric Data Sets after Viking (1 of 2)

- **Earth-Based Observations (continuing)**
  - ***Ground-based observations at microwave wavelengths***
  - ***Hubble Space Telescope***
- **Phobos-2 Mission (Feb.-March, 1989)**
  - ***Termoscan: surface temperatures and atmospheric dust properties***
  - ***Solar Occultations: atmospheric profiles (T, aerosols, condensates, water)***
- **Mars Pathfinder (July-Sept., 1997)**
  - ***IMP: Sky views***
    - **Atmospheric opacity, cloud and haze structure**
    - **Mesoscale phenomena (e.g., dust devils)**
  - ***MET: Near-surface pressure, temperature and wind***
    - **Diurnal variations**
    - **Dust Devil signatures**

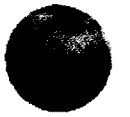
Atmospheric Data Sets after Viking (2 of 2)

Mars Reference Atmosphere

- **Mars Global Surveyor (1997 -)**
  - ***MOLA: Topography and mass balance***
  - ***TES: Atmospheric profiles, polar cap monitoring, surface properties***
  - ***MOC: Daily global mosaics of atmospheric & surface phenomena***
  - ***RS: High-vertical-resolution profiles from radio occultations***
  - ***MAG/ER: Upper atmospheric structure and magnetic field***
  - ***ACCEL: Upper atmospheric densities & scale heights during aerobraking***

- **2001 Mars Odyssey (2001 -)**
  - ***THEMIS: Monitoring mid-level atmospheric T & polar phenomena***
  - ***GRS: Detection of water (hydrogen) in topmost meter of ground***
  - ***ACCEL: Upper atmospheric densities & scale heights during aerobraking***

Major Advances since Viking (my view!)

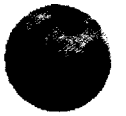


Mars Reference Atmosphere

- **Atmospheric water is a major player in Mars climate through its role in removing atmospheric dust [*Clancy, Rodin et al.*]**
  - ***Ice condensation and scavenging of dust is a major control of water vapor and atmospheric dust distributions in the current climate and potentially in past climates***
    - **Drives part of the difference between northern & southern hemispheric seasonal activity; probably not a driver of interannual variability**

- **Large-scale topographic differences exert a major control on atmospheric circulation and transport [*Richardson, Wilson*]**
  - ***Western boundary currents, northern wave activity***
  - ***Control on Hadley-type circulations may damp variations due to orbital variations on astronomical time scales***

Major Advances since Viking (my view!)



— *Mars Reference Atmosphere*

(continued)

- **Seasonal variations are very predictable up to a point [*Malin et al.*]**
  - ***Onset of local dust storms & mesoscale activity (e.g., dust devils)***
  - ***Once dust-raising systems are active (and ice-scavenging removal is lessened?), atmosphere is less predictable***

  ⇒Northern spring and summer seasons are less variable (up to Ls ~ 165?) than southern spring and summer

- **Repeating seasonal activity may trigger interannual variation [*Leovy et al.*] but triggers for southern subtropical dust storms may come from north (*Richardson et al.*) or south?!**

- **Waves generated in the lower atmosphere *really* do make into the upper atmosphere, particularly the diurnal Kelvin wave [*Keating, Wilson, Forbes, et al.*]**

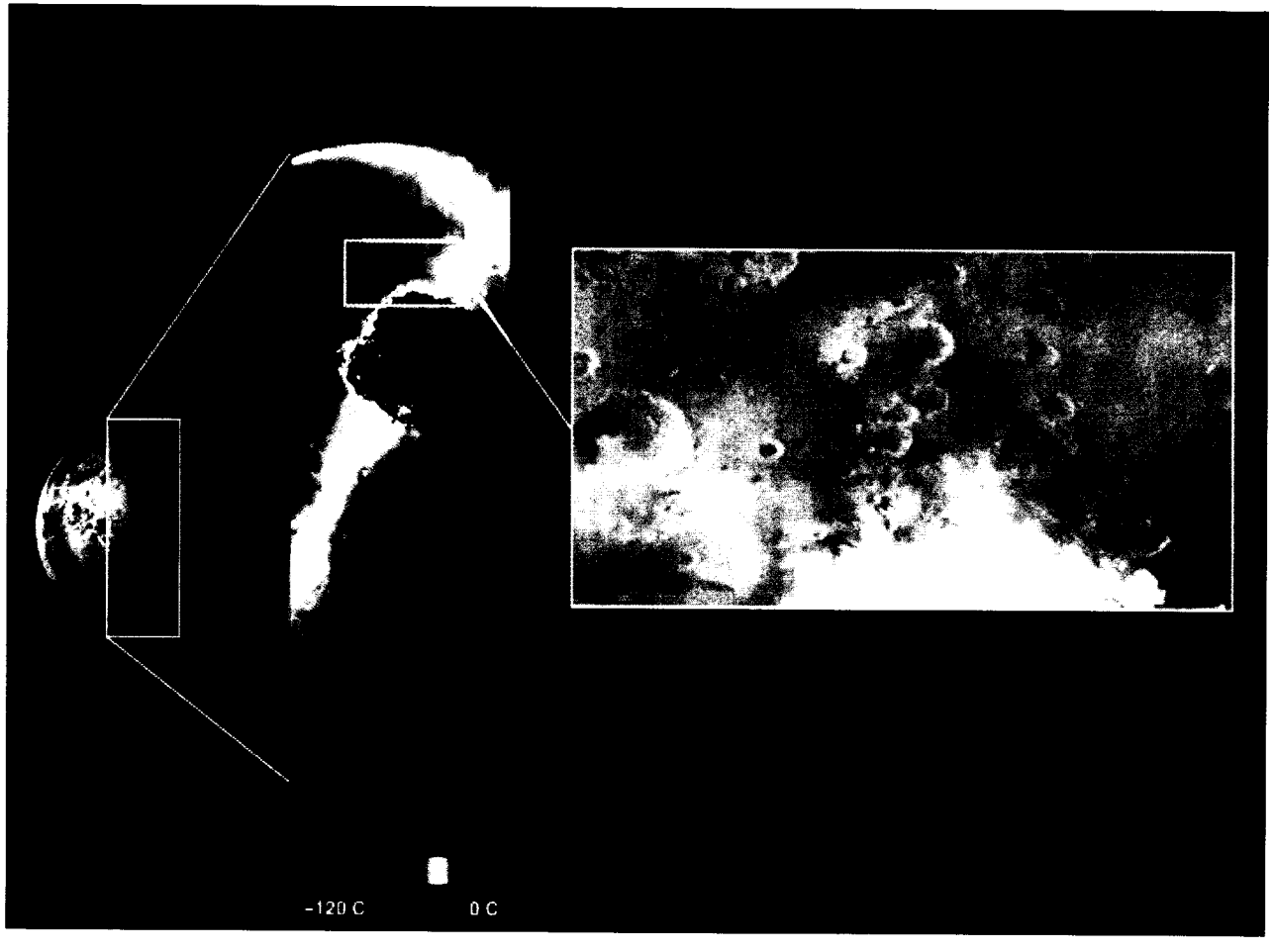
HST View in 2001

— *Mars Reference Atmosphere*

CREDIT: NASA / STScI / AURA / J. Bell & M. Wolff

South Pole in Late Summer

— *Mars Reference Atmosphere*



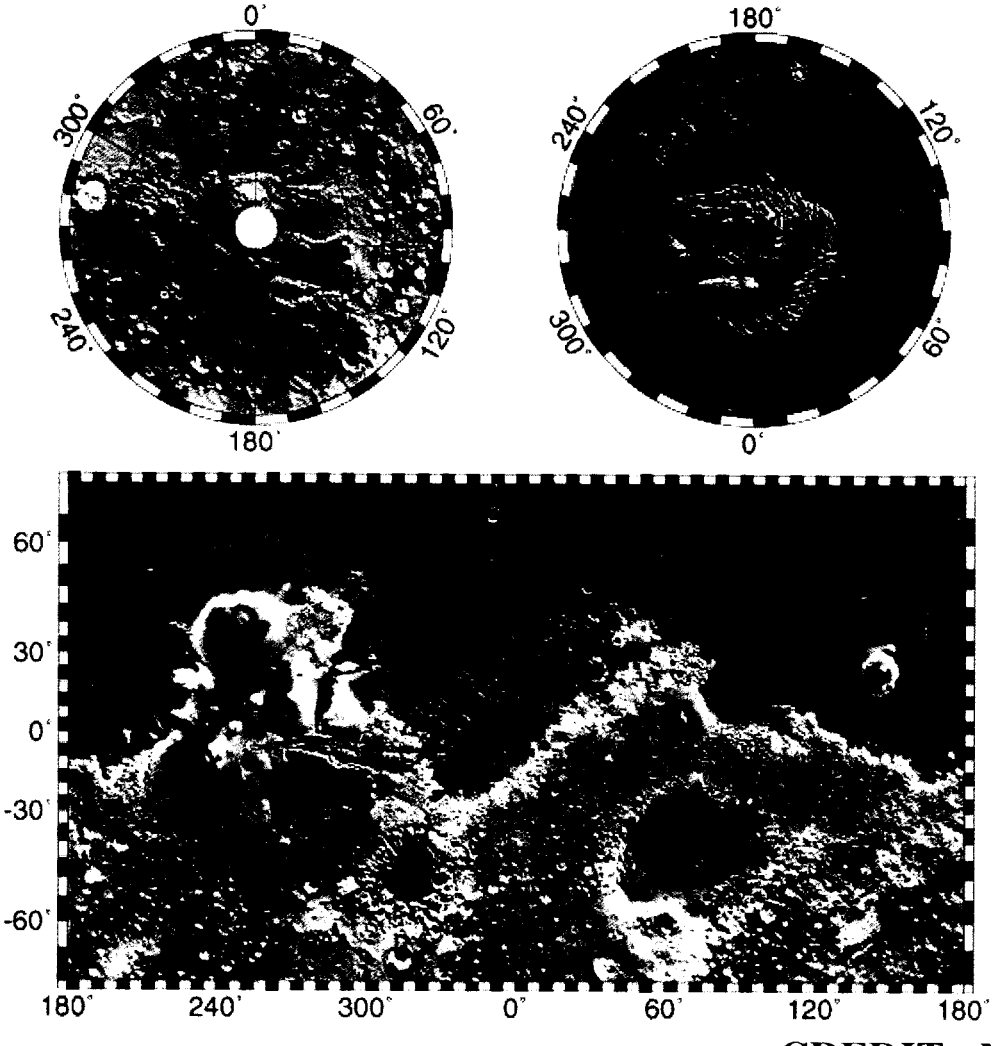
Impact of New Data Sets

Of the new data sets, Mars Global Surveyor is likely to have the greatest impact on understanding atmospheric phenomena:

- ***Systematic Coverage***
  - **Daily, Global Sampling key to understanding time-varying fields**
  - **Multiple Observing Systems (e.g., visible and thermal IR)**
- ***Long Record***
  - **Comparison of different Mars years is key to understanding Interannual Variability**
  - **MGS now in third Mars year of observations**
  - **MGS observational record includes years with and years without a global dust storm**

Mars Topography (MGS MOLA)

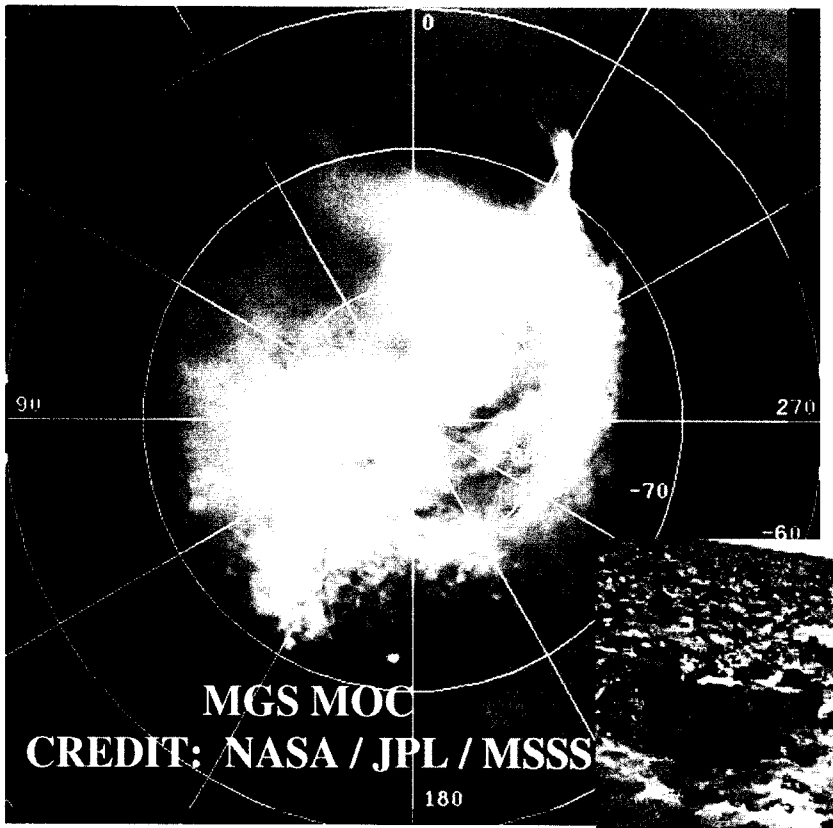
— *Mars Reference Atmosphere*



CREDIT: NASA / JPL / GSFC

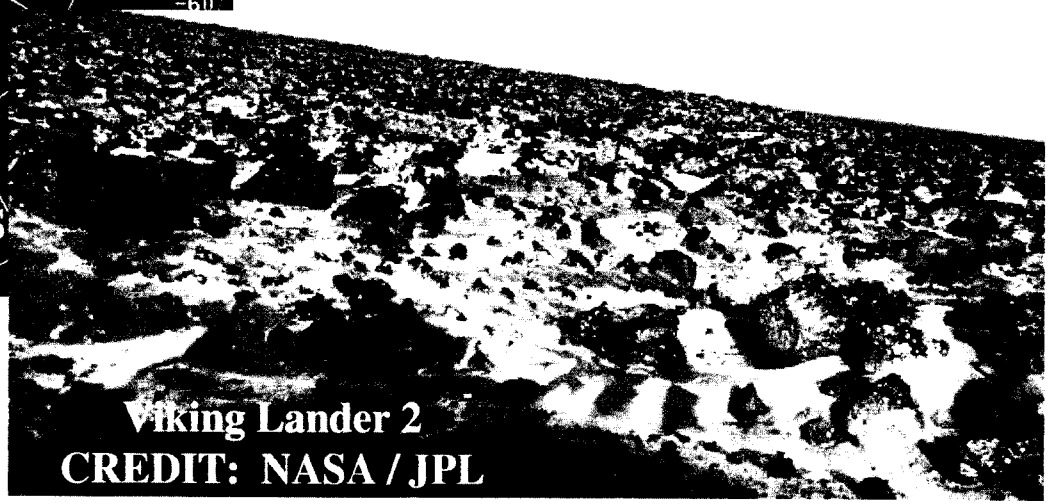
CO_2 Cycle: Seasonal Frosts

— *Mars Reference Atmosphere*



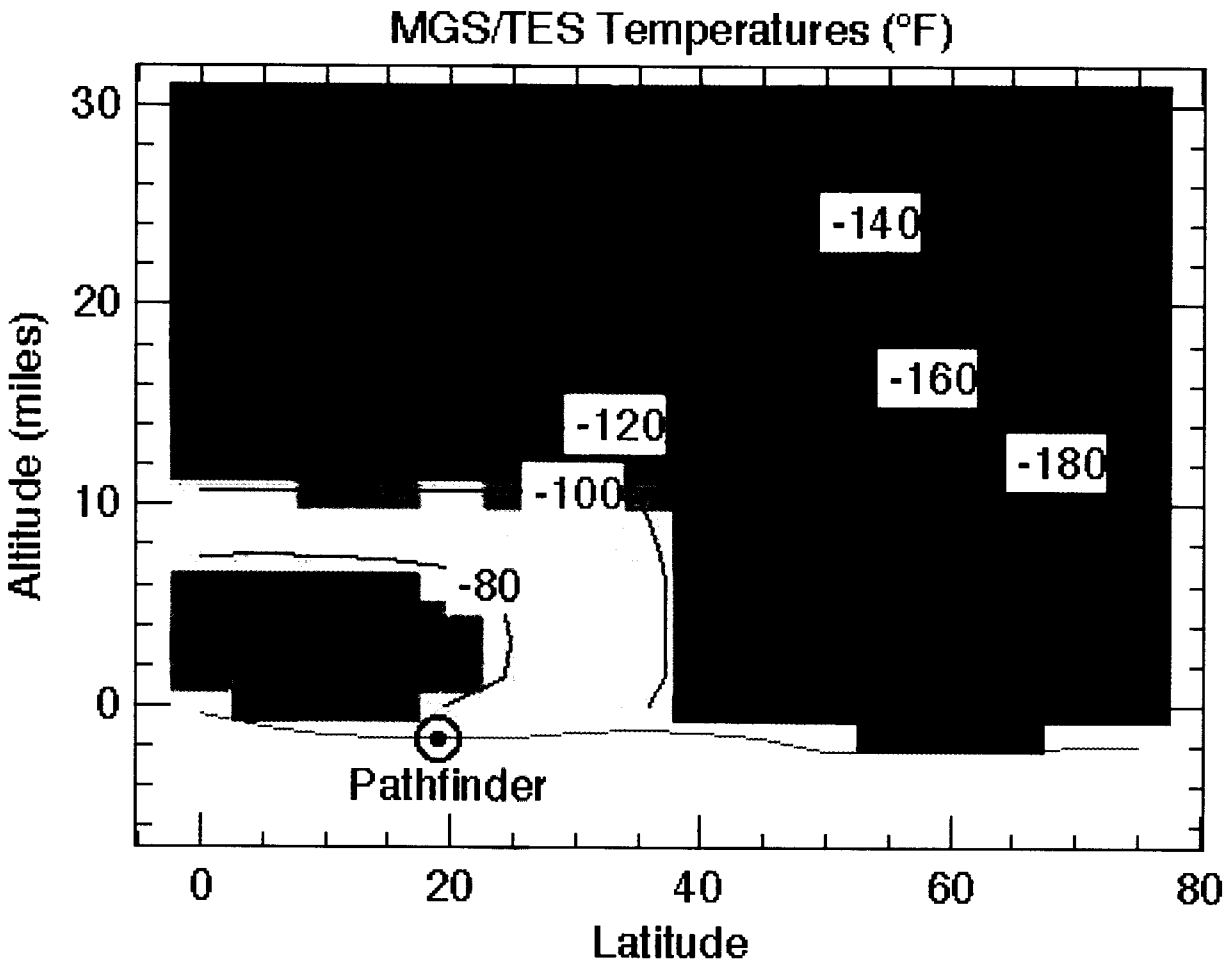
← South Pole in late summer

Northern mid-latitudes (48N) in late winter



Zonal Temperatures in N. Winter

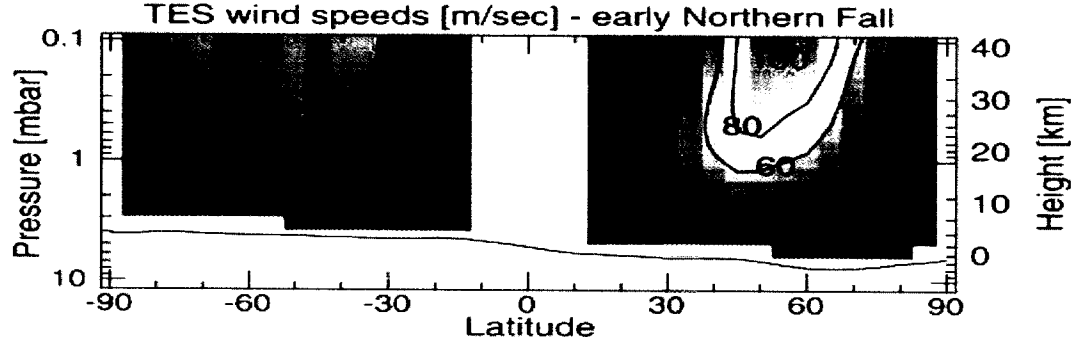
— *Mars Reference Atmosphere*



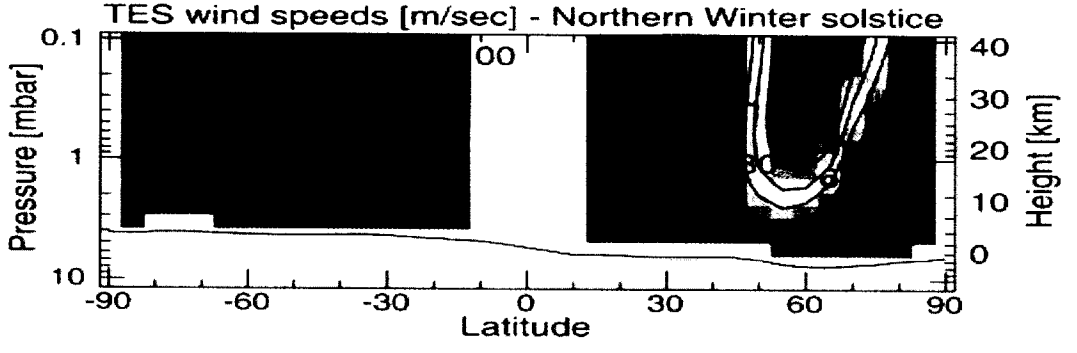
CREDIT: NASA / JPL / ASU

Geostrophic Winds

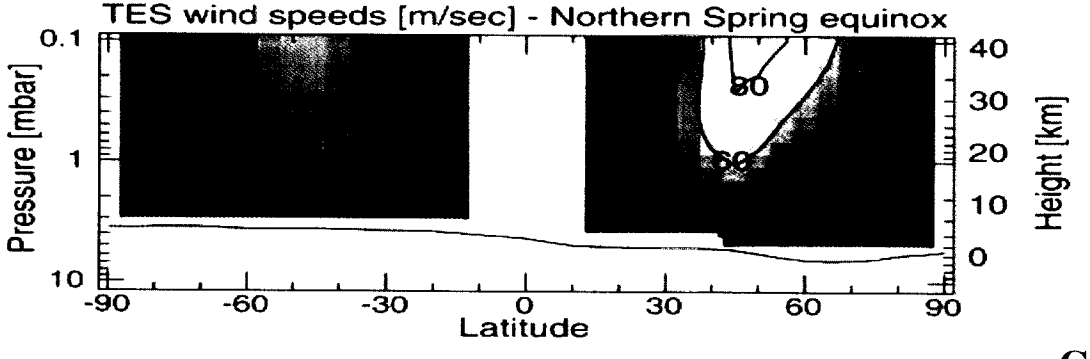
— *Mars Reference Atmosphere*



Early Southern Spring
Early Northern Fall



N. Winter Solstice S.
Summer Solstice
(near perihelion)



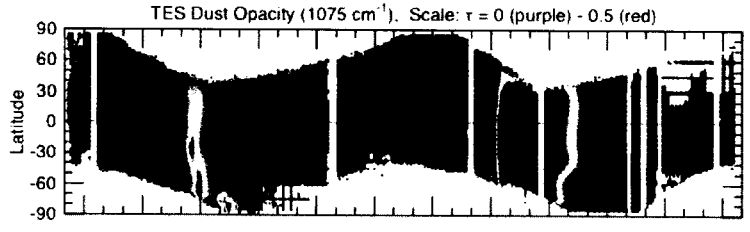
Vernal Equinox

CREDIT: NASA / JPL / ASU

MGS TES Climatology

— *Mars Reference Atmosphere*

Dust



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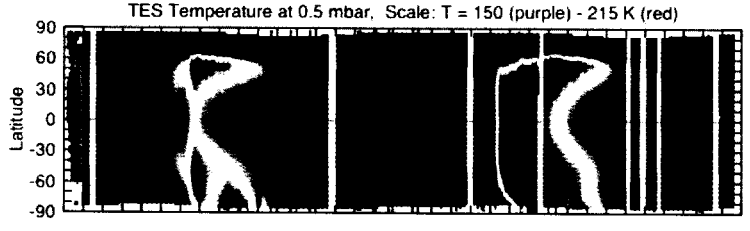

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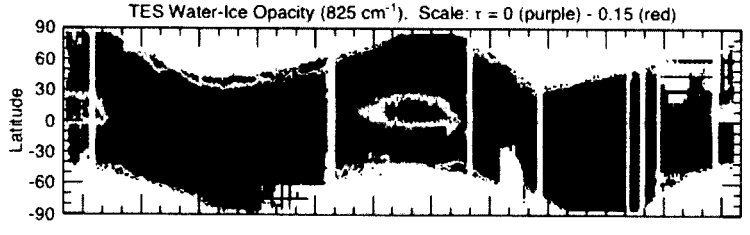
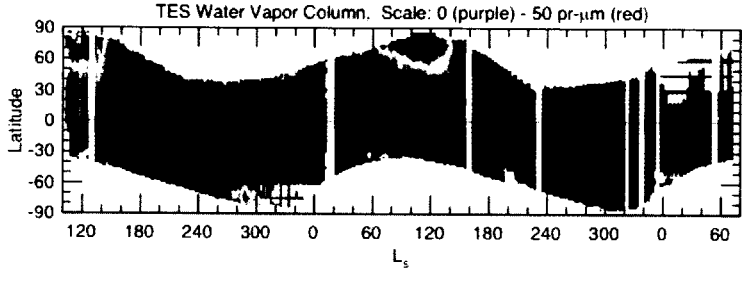


Water Vapor



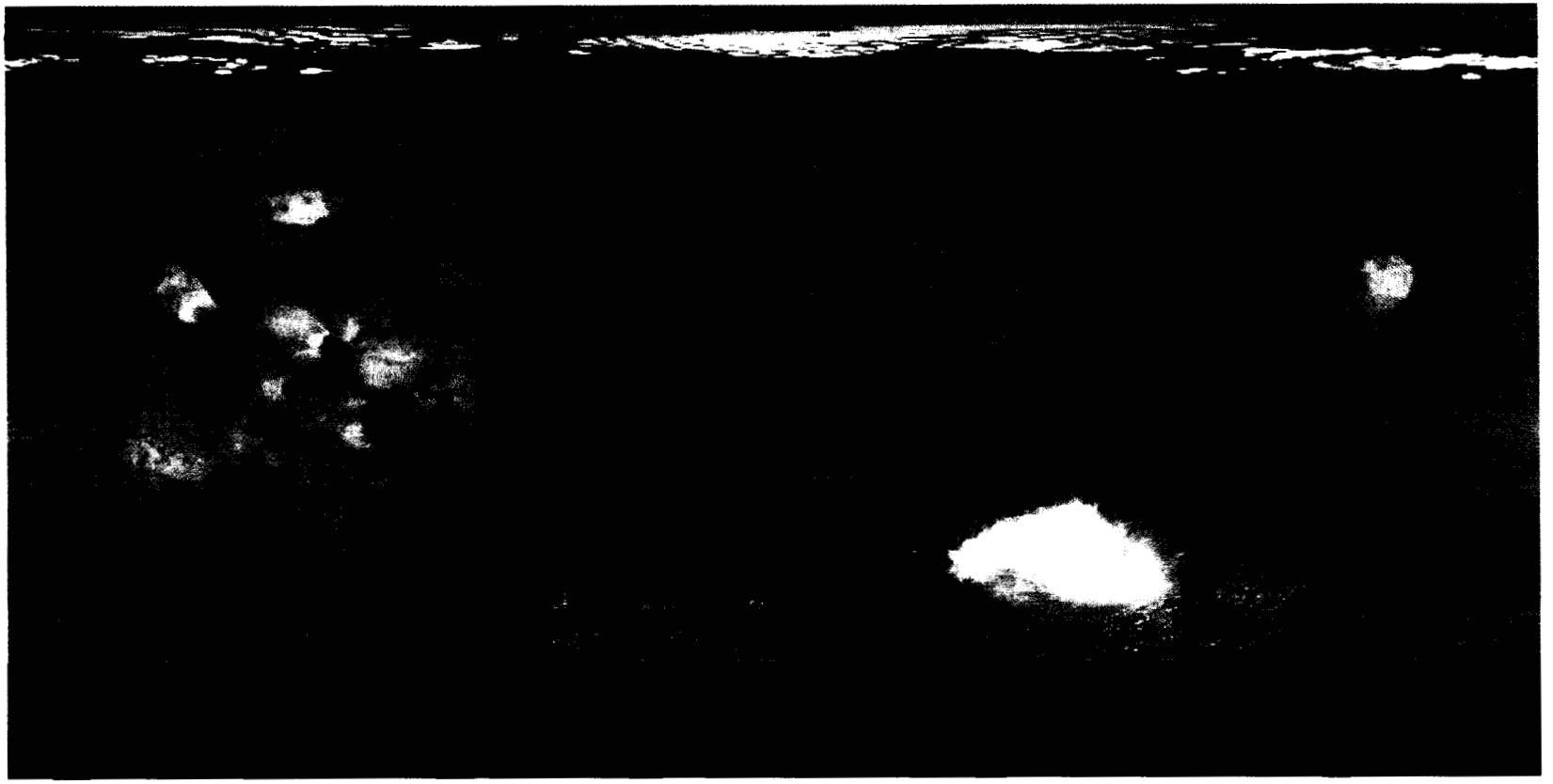
Zonally Averaged Fields during Two Mars Years

Courtesy of
M. Smith
TES Team

(TES PI: P. Christensen)
NASA/JPL/ASU/GSFC

Equatorial Cloud Belt (Mars ITCZ?)

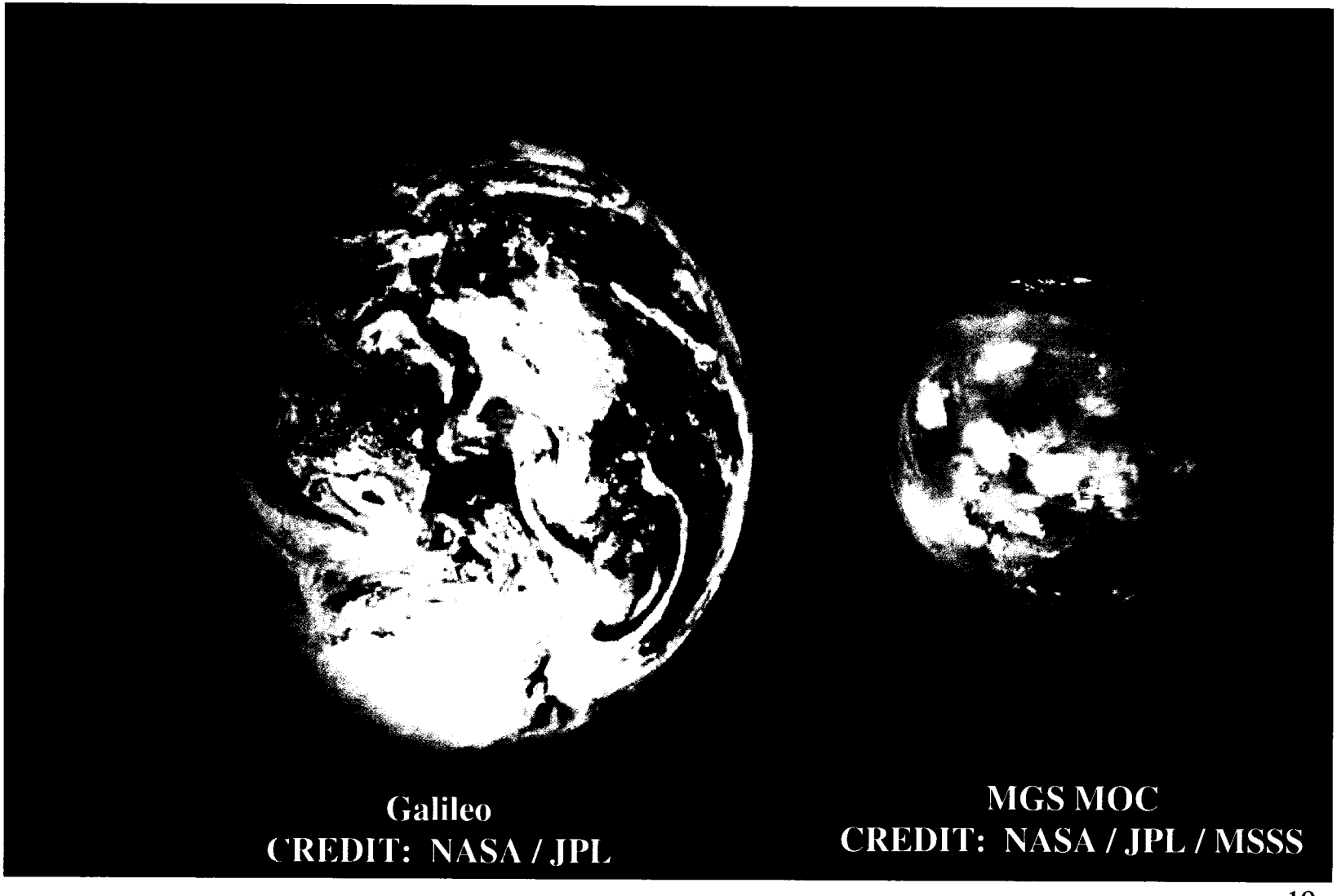
— *Mars Reference Atmosphere*



MGS MOC (PI: M. Malin)
CREDIT: NASA / JPL / MSSS

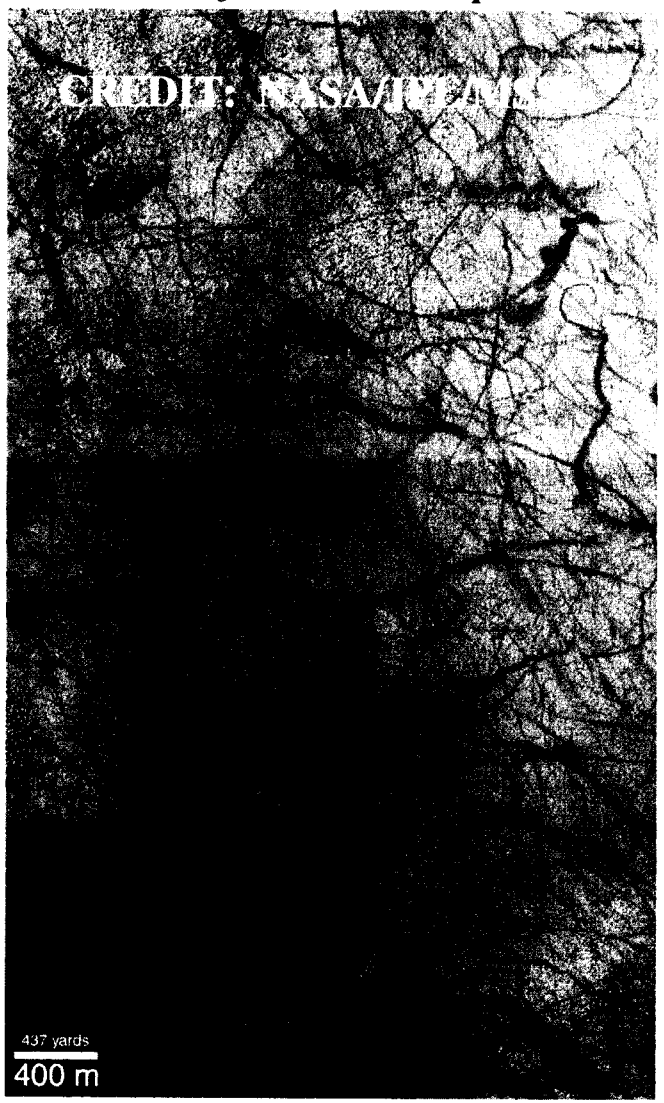
Earth & Mars

— *Mars Reference Atmosphere*



How to Raise Dust on Mars

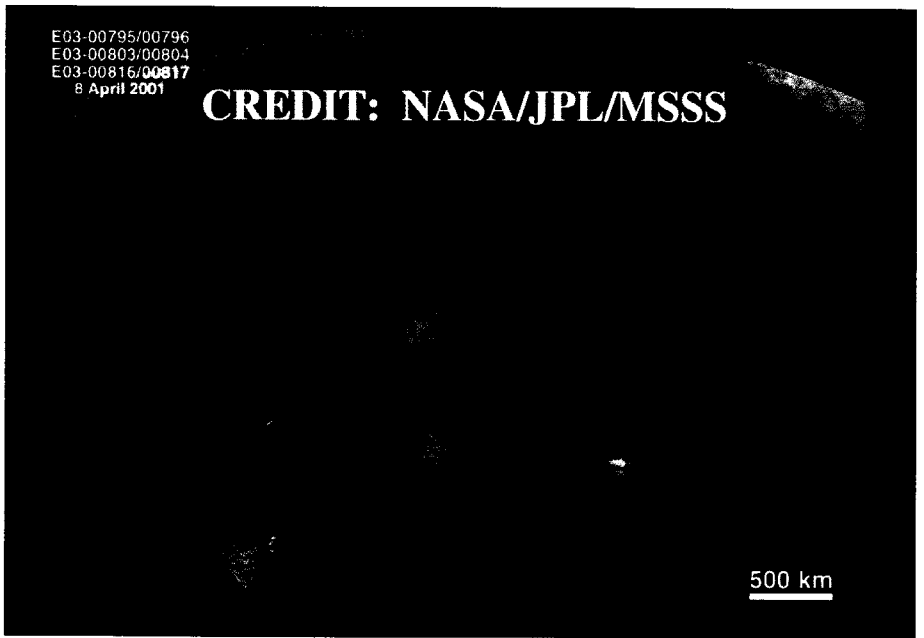
— *Mars Reference Atmosphere*



MGS Mars Orbiter Camera (MOC)
PI: M. Malin (MSSS)

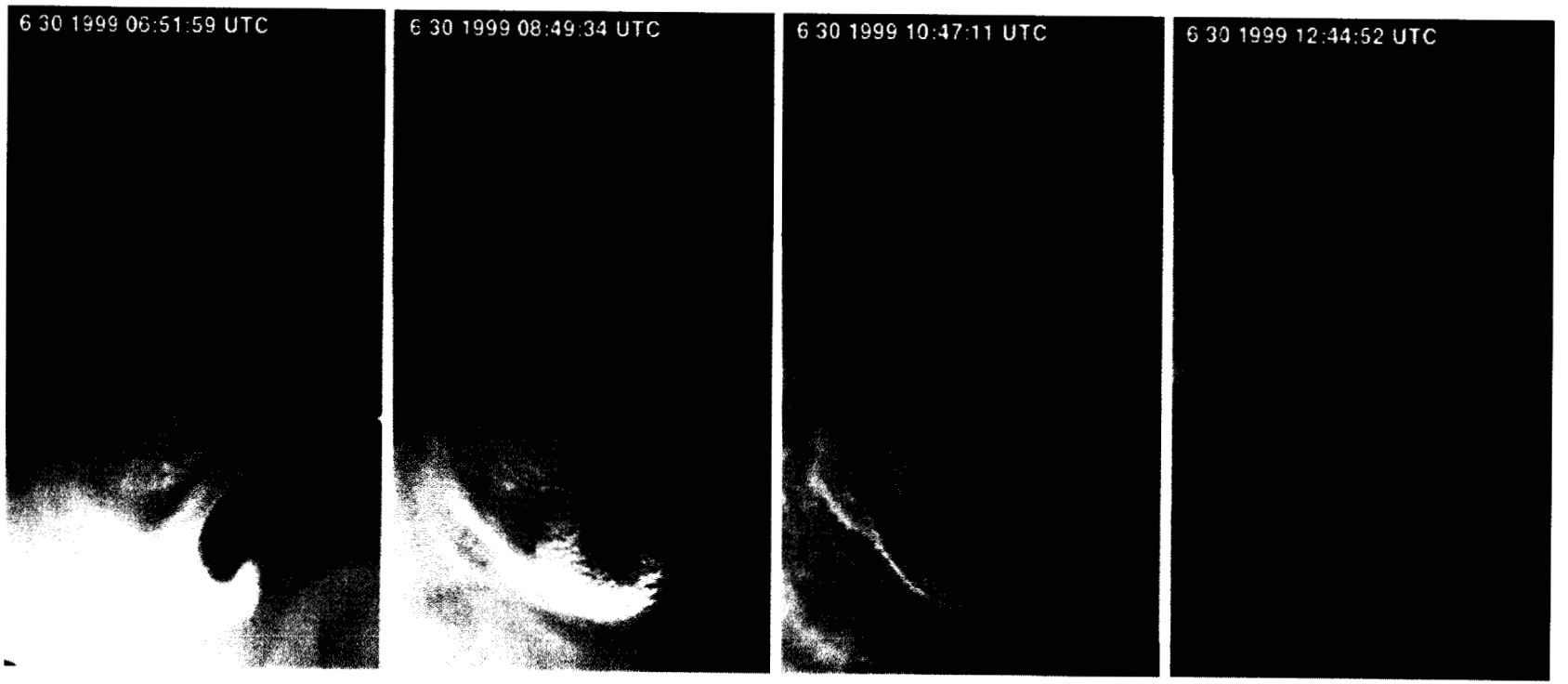
← ***Dust Devil Tracks***

Local Dust Storm at South Pole Cap Edge



North Polar Dust Storm

— *Mars Reference Atmosphere*

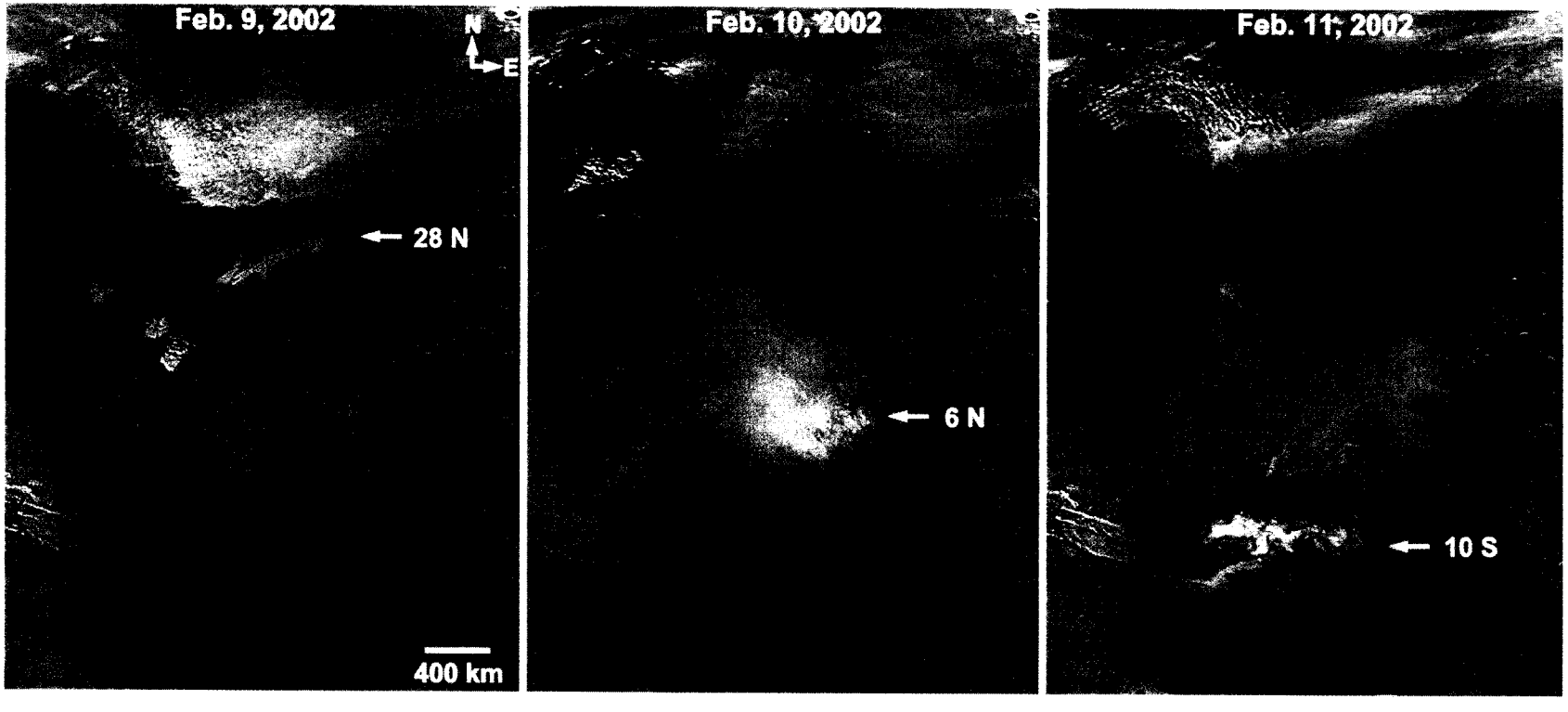


Viewed on Consecutive MGS Orbits (~ 2 hrs apart)

MGS MOC
CREDIT: NASA / JPL / MSSS

Northern Storm Paths

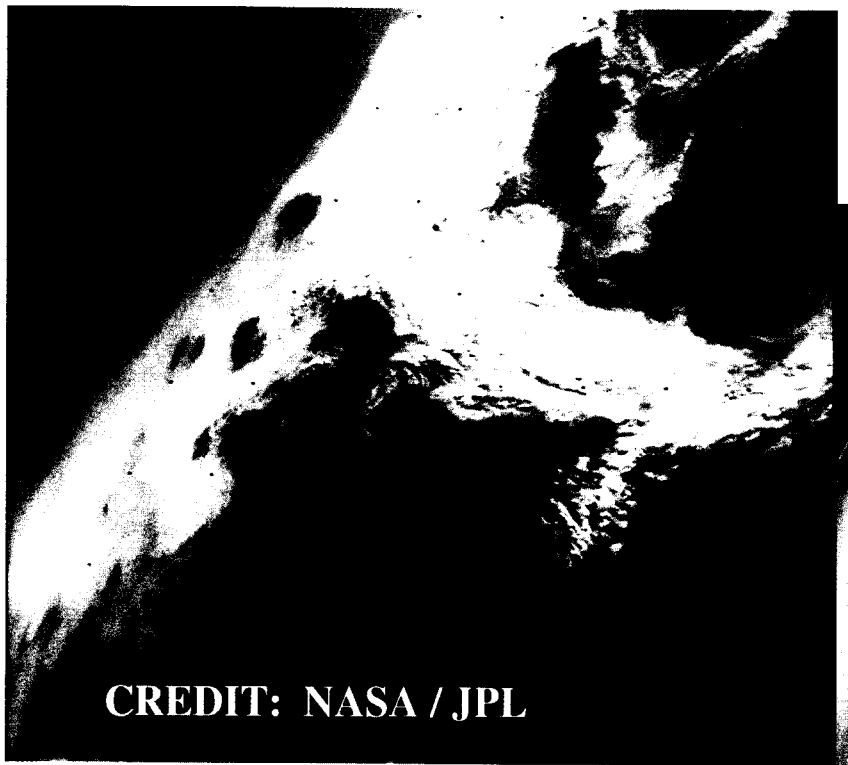
— *Mars Reference Atmosphere*



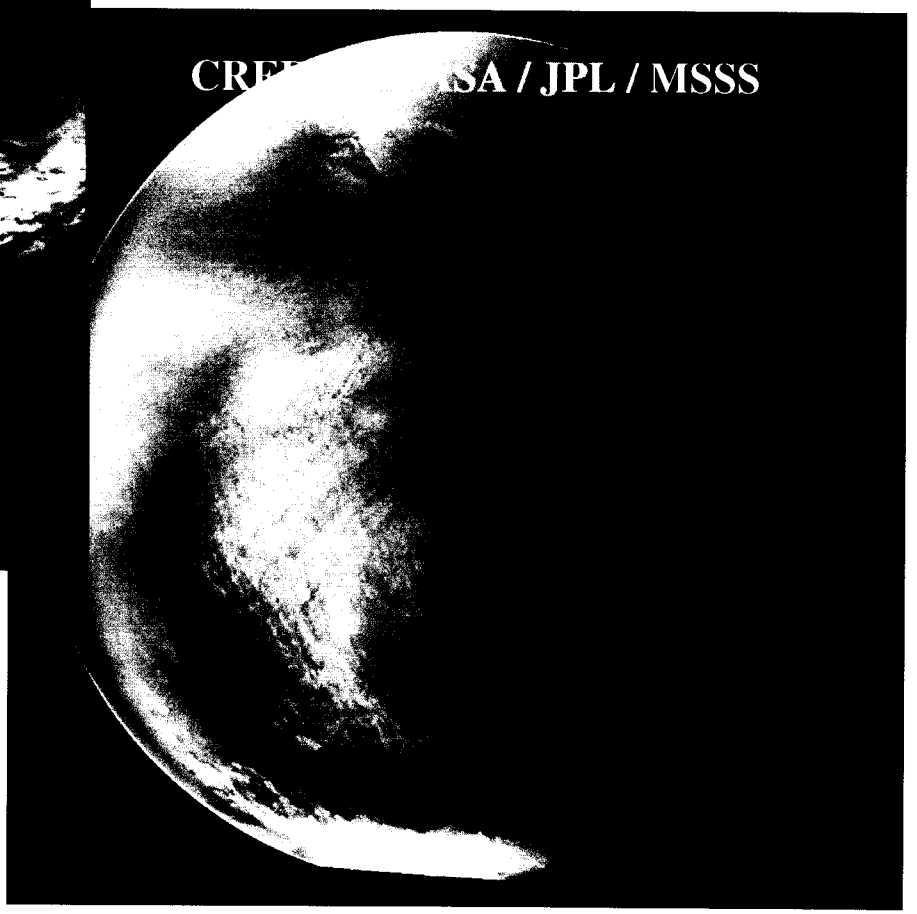
MGS MOC
CREDIT: NASA / JPL / MSSS

Two Faces of Dust Storm Onset

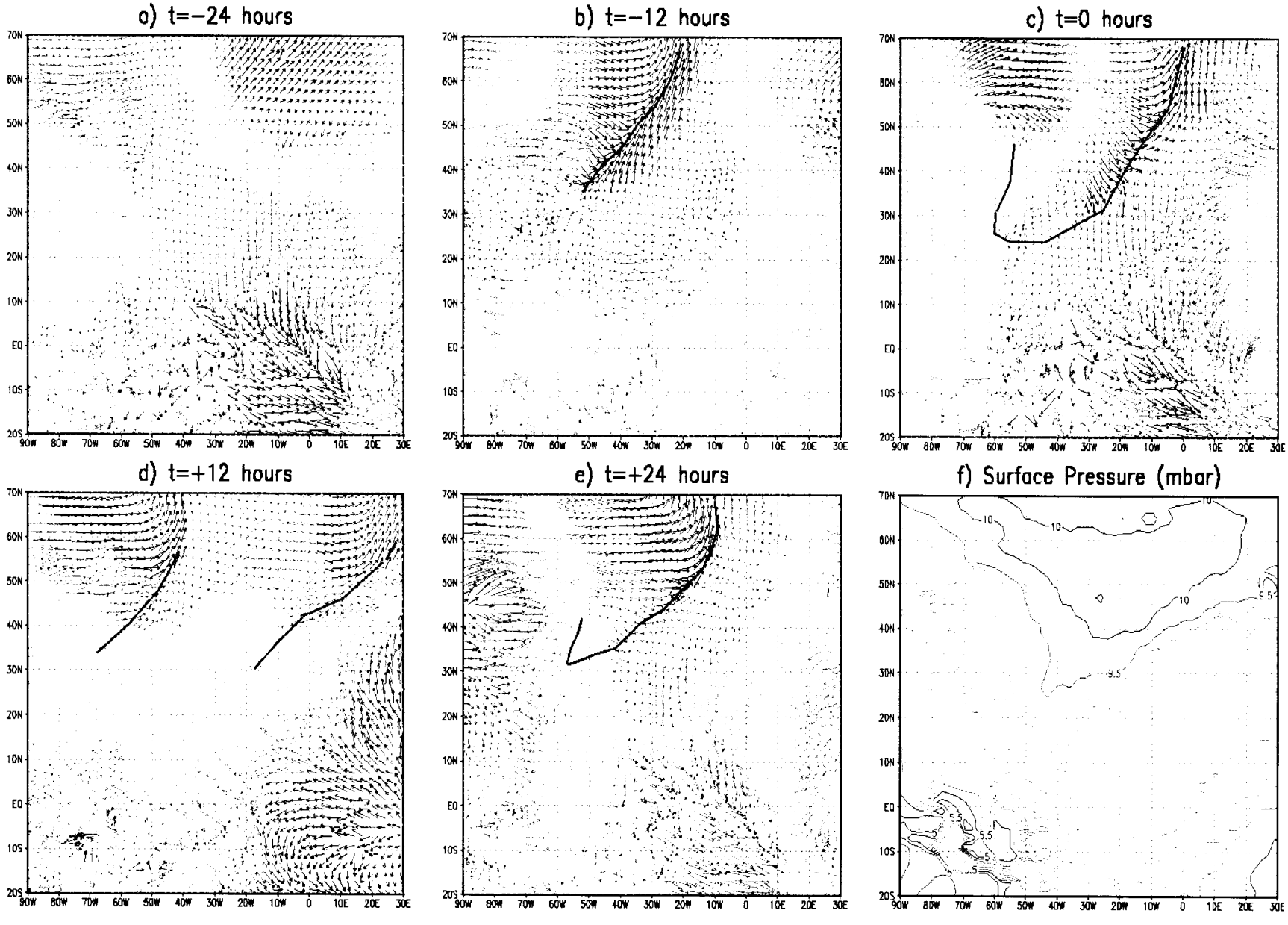
Mars Reference Atmosphere



← Viking views the 1977a GDS



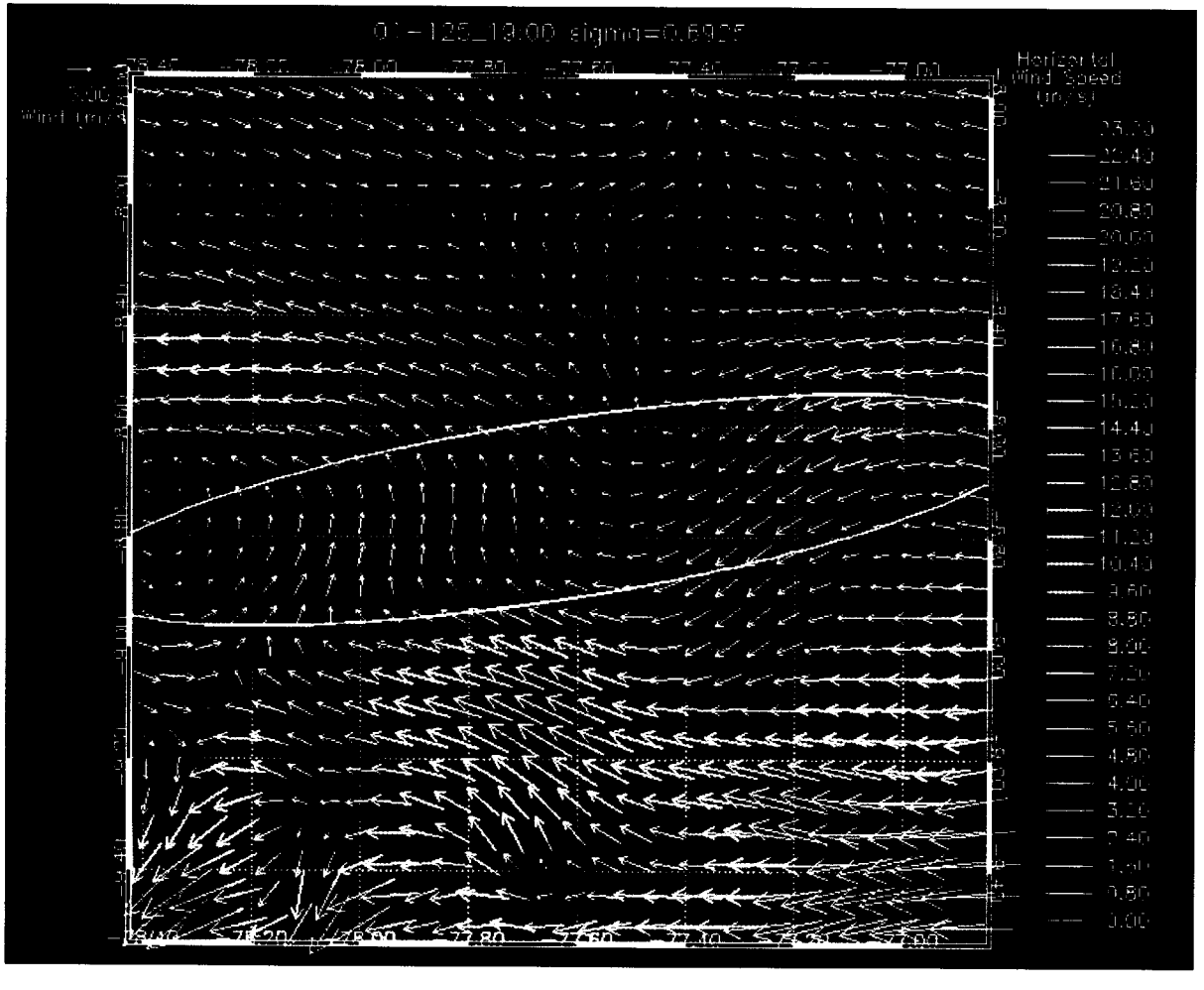
MGS views the 2001 GDS →



TIDAL GATE for FRONTS: H. Wang, et al., manuscript in preparation rwz-24

Mesoscale Modeling: Melas Chasma

— *Mars Reference Atmosphere*



Courtesy of S. Rafkin: MRAMS Simulation for MER

Limitations of Current Data

— *Mars Reference Atmosphere*

- **Current Limitations w.r.t. Dynamical Meteorology**
  - ***Restricted altitude range for global coverage (< 80 km)***
  - ***Restricted local time coverage***
  - ***Limited spatial resolution (horizontal and vertical)***
    - **Especially near surface**
  - ***Lack of concurrent surface pressure data***
  - ***No independent wind data!***
  - ***Little independent validation (e.g., using different data types)***

⇒ Continued Dependence on Atmospheric Models for Scientific Understanding

  - ***Fortunately, atmospheric models have improved***
    - **Improved resolution, vertical range, & physical parameterization**
    - **Still need vigorous validation**
  - ***Models can reveal observational faults or inconsistencies***

⇒ Continued Dependence on Parametric Engineering Models

Future Atmospheric Data Sets (1 of 2)

Mars Reference Atmosphere

- **Mars Express (arrives in 2003/2004)**
  - ***Elliptical 8 hr orbit, 250 km periapsis***
  - ***Planetary Fourier Spectrometer (PFS): Atmospheric Profiles (nadir viewing) and surface observations***
  - ***OMEGA: Column abundances of atmospheric water vapor and aerosols in addition to surface composition***
  - ***SPICAM: UV solar/stellar occultations and UV emission for atmospheric structure and aerosol abundances and upper atmospheric composition; NIR for column water amounts***
  - ***HRSC: High-resolution stereo imaging of mesoscale phenomena***
  - ***MARSIS: Polar ice cap structure***
- **NOZOMI (arrives in 2003/2004)**
  - ***Mission geometry in revision***
  - ***Upper atmospheric data at different local times***

Future Atmospheric Data Sets (2 of 2)

Mars Reference Atmosphere

- **Mars Reconnaissance Orbiter (arrives in 2006)**
  - *Near-circular polar orbit, 265-320 km, frozen over S. Pole*
  - *Mars Climate Sounder (MCS: PMIRR rebuild): Daily Limb Sounding and Polar Monitoring*
  - *CRISM: Seasonal Monitoring with EPF-type profiles, column abundances of dust, water vapor*
  - *MARCI: Daily, Global Monitoring in UV and VIS channels*
  - *HiRISE: High-resolution imaging of mesoscale phenomena, including dust storm onsets*
  - *GRAVITY & RS: Tracking mass movement; occultation data (?)*
  - *SHARAD: Near-surface water/water ice reservoirs?*
- **NetLanders/Premiere (launched in 2007?)**
  - *Surface meteorological measurements at 4 stations*
  - *IR/Microwave sounding from Orbit (?)*
  - *Global Weather Monitoring (?)*

Reference Atmosphere

- ***Build on MGS data***
  - **Use MGS data to validate atmospheric models**
  - **Use models to fill in unobserved domains and to extend to different times (especially other times of day, solar cycle)**
  - **Use models to estimate unobserved, or loosely constrained, fields (e.g., near-surface winds)**
- ***Update as Odyssey, Mars Express, NOZOMI, MRO, Netlander data become available***
- ***Explore engineering sensitivities parametrically***
  - **Use available data as broad constraints**
  - **Use atmospheric models to estimate potential scenarios**

Current observations of Mars have shown a fascinating range of atmospheric structure, variability and interaction which continues to challenge us